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AERODYNAMIC CHARACTERISTICS OF AN EJECTION SEAT ESCAPE SYSTEM WITH A STABILIZATION PARACHUTE AT MACH NUMBERS FROM 0.3 THROUGH 1.2

David E. A. Reichenau

ARO, Inc.

 PER TAB 74-26 DTD 20 Dec, 74

April 1972

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AERODYNAMIC CHARACTERISTICS OF AN EJECTION SEAT ESCAPE SYSTEM WITH A STABILIZATION PARACHUTE AT MACH NUMBERS FROM 0.3 THROUGH 1.2

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FOREWORD

The work reported herein was sponsored by the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio, under Program Element 62201F.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-72-C-0003. The test was conducted in the Propulsion Wind Tunnel (16T) from January 7 to 19, 1972, under ARO Project No. PB0255. The manuscript was submitted for publication on March 9, 1972.

This technical report has been reviewed and is approved.

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ABSTRACT

A test was conducted in the 16-ft Transonic Wind Tunnel of the Propulsion Wind Tunnel Facility to determine the aerodynamic characteristics of a 0.5-scale ejection seat escape system and to determine the stability effects of a stabilization parachute attached to the back of the ejection seat model. The results were obtained for both simulated rocket-off and rocket-on conditions through a model angle-of-attack range from 0 to 30 deg and an angle-of-yaw range from 0 to 15 deg. High-pressure air was used to simulate the escape rocket jet plume at a sea-level altitude. Over the test range of this investigation, the results show that the ejection seat model was statically unstable but became longitudinally and directionally stable with the parachute using the three- and four-point bridle assemblies. Jet simulation and model yaw angle had little effect on the ejection seat longitudinal stability; however, jet simulation increased the parachute drag coefficient.

CONTENTS

APPENDIX
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NOMENCLATURE

b	Model reference length, 2.0 ft
C_A	Model axial-force coefficient, $F_A/q_\infty S$
C_{D_o}	Parachute drag coefficient, $D_p/q_\infty S_o$
C_ℓ	Model rolling-moment coefficient, $M_\ell/q_\infty Sb$
C_m	Model pitching-moment coefficient, $M_m/q_\infty Sb$
C_N	Model normal-force coefficient, $F_N/q_\infty S$
C_n	Model yawing-moment coefficient, $M_n/q_\infty Sb$
C_Y	Model side-force coefficient, $F_Y/q_\infty S$
D	Model reference width, ft
D_p	Parachute drag force, lb
F_A	Model axial force, lb
F_N	Model normal force, lb
F_Y	Model side force, lb
M_ℓ	Model rolling moment, ft-lb
M_m	Model pitching moment, ft-lb

M_n	Model yawing moment, ft-lb.
M_∞	Free-stream Mach number
p_c	Nozzle total pressure (chamber pressure), psfa
p_∞	Free-stream static pressure, psfa
q_∞	Free-stream dynamic pressure, psf
S	Model reference area, 1.73 ft^2
S_o	Parachute reference area, 4.906 ft^2
X	Axial location of parachute downstream of the model center-of-gravity location, positive downstream, ft
α	Angle of attack, deg
ψ	Angle of yaw, deg
NOTE:	The force and moment coefficients are in the body-axis system (Fig. 7).

SECTION I
INTRODUCTION

A series of tests have been conducted in the Propulsion Wind Tunnel (16T) to determine the aerodynamic characteristics of an ejection seat escape system and to improve the escape seat stability after separation from the aircraft. In June and July 1969, a 0.5-scale ejection seat escape system was tested with a simulated catapult rocket over a wide range of model attitudes. The results of the investigation are presented in Ref. 1 and show the basic ejection seat aerodynamic characteristics and the aerodynamic interference effects of the simulated rocket plume on the ejection seat aerodynamic characteristics. In September 1970, the same model was tested to determine the flow field in the wake of the ejection seat and to determine the performance characteristics of a stabilization parachute attached to the ejection seat model at various trail distances. The results are presented in Ref. 2 and show that the ejection seat model was statically unstable (over the test range of that investigation) but became longitudinally stable with the parachute.

The results reported herein were obtained with the 0.5-scale ejection seat model modified to accommodate different bridle assemblies attaching the parachute to the seat with the stabilization parachute trailing at a constant distance behind the model. The data were obtained during simulated rocket-off and rocket-on conditions at free-stream Mach numbers from 0.3 to 1.2 for angles of attack from 0 to 30 deg and angles of yaw from 0 to 15 deg. High-pressure air was used to simulate a sea-level altitude escape rocket jet plume.

SECTION II
APPARATUS

2.1 TEST FACILITY

Propulsion Wind Tunnel (16T), Transonic, is a closed-circuit, continous flow wind tunnel capable of being operated at Mach numbers from 0.20 to 1.60. The test section is 16 by 16 ft in cross section and 40 ft long. The tunnel can be operated within a stagnation pressure range from 120 to 4,000 psfa depending on the Mach number. Stagnation temperature can be varied from an average minimum of about 80 to a maximum of 160°F. Perforated walls in the test section allow continuous operation through the Mach number range with a minimum of wall interference.

Details of the test section showing the model location and support system arrangement are presented in Fig. 1 (Appendix). Installation photographs showing the model with and without a stabilization parachute in Tunnel 16T are presented in Fig. 2. A more extensive description of the tunnel and its operating characteristics is contained in Ref. 3.

2.2 TEST ARTICLE

The model tested consisted of a 0.5-scale representation of an ejection seat escape system occupied by a dummy crew member of average size in normal flying clothes and equipment. The model has a frontal area of 1.73 ft^2 and a side area of 1.71 ft^2. Major

dimensions of the model are presented in Fig. 3. The escape rocket was positioned in the lower aft portion of the seat and was attached to the sting in such a manner as to isolate the model from the jet reaction force.

The crew member, constructed of cloth impregnated with phenolic resin, was rigidly attached to the metal seat housing a six-component balance. The arms of the dummy crew member were simulating an ejection position holding the ejection handle control on the arm rests. The nozzle configuration used simulated the plume shape of a full-scale 2174-518 rocket catapult at an altitude of sea level. The fixed-area-ratio nozzle was designed so that the initial turning angle of the jet plume simulated the initial turning angle of the 2174-518 rocket plume at sea-level altitude (Ref. 4). Details of the nozzle are given in Fig. 4. High-pressure air, supplied to the nozzle through the center of the sting support system, was controlled remotely. A hydraulic actuator was used to provide remote variation of the model angle of attack through the range of 30 deg. Model yaw angles were achieved by rotating the model and sting support system about the vertical axis with a roll mechanism installed in the wall of the test section.

The stabilization parachute assemblies are shown in Fig. 5. The parachute riser line was affixed to the back of the ejection seat by a bridle-load link combination. A strain-gage load link was placed in each of the bridle legs, and a load link, measuring the total parachute drag, was placed between the riser line and the bridle assembly. A hemisflo parachute, constructed of 0.75-inch nylon ribbon with a nominal diameter of 2.50 ft and a geometric porosity of 15 percent, was used as the stabilization parachute. A dimensioned sketch of the hemisflo parachute is presented in Fig. 6.

2.3 INSTRUMENTATION

An internally mounted, six-component strain-gage balance was used to measure the model forces and moments. Strain-gage load links were used to measure the parachute drag loads exerted on each bridle leg at the model attachment points and another load link was used to measure the total parachute drag between the bridle and riser line. The jet chamber pressure and temperature were measured with a 0- to 3000-psi gage transducer and a copper-constantan thermocouple, respectively.

The electrical output signals from the balance, load links, pressure transducer, and the thermocouple were transmitted through analog-to-digital converters to a Raytheon 520 computer for final data reduction while the test was in progress. Also, the balance and load link outputs were continuously recorded on direct-writing oscillographs for monitoring model dynamics and parachute drag. Five motion-picture cameras and a television camera were used to document and monitor the test.

SECTION III
TEST DESCRIPTION

3.1 GENERAL

The deployment of the stabilization parachute was accomplished by permitting the parachute to hang freely from the ejection seat model and deploy as the tunnel conditions

were achieved. After the prescribed tunnel conditions were established, jet-off and jet-on data were obtained while holding the free-stream Mach number constant and varying the model angle of attack at discrete model yaw angles. Four different bridle assemblies were used to attach the stabilization parachute to the model at a trailing distance of X/D = 7.8. The parachute steady-state loads were calculated by averaging the analog output from the load links and balance over 1-sec intervals.

For the jet-on data, a continuous supply of high-pressure air was ducted to the model for rocket simulation. The nozzle design and jet pressure used during these tests simulated the full-scale rocket plume shape at a sea-level altitude. (It should be mentioned that the full-scale rocket catapult operates at a constant chamber pressure of 4000 psia, but in order not to exceed the load limit of the balance over the Mach number range it was necessary to reduce both the jet chamber and free-stream static pressures while maintaining the pressure ratio (p_c/p_∞) constant. The jet chamber pressure was varied from 1600 psia to M_∞ = 0.30 to 387 psia at M_∞ = 1.20.)

The ejection seat model was tested at free-stream Mach numbers from 0.30 to 1.20 through a model pitch and yaw range from 0 to 30 deg and 0 to 15 deg, respectively. The dynamic pressure was varied from 175 to 302 psf, and the Reynolds number per foot was varied from 1.12 x 10^6 to 2.30 x 10^6.

3.2 DATA REDUCTION

The model force and moment data obtained during this test were corrected for weight tares and reduced to coefficient form in the body-axis system as shown in Fig. 7. The moment coefficients are referred to the model reference center-of-gravity position shown in Fig. 3. All model force and moment coefficients are based on the seat height of 2 ft and projected model frontal area of 1.73 ft^2. The force and moment coefficients do not include the jet reaction force.

3.3 PRECISION OF MEASUREMENTS

An estimate of the precision of measurements is presented below:

M_∞	$\pm M_\infty$	$\pm\alpha$	$\pm C_A$	$\pm C_N$	$\pm C_M$	$\pm C_{D_p}$	$\pm C_Y$	$\pm C_n$	$\pm C_\ell$
0.6	0.005	0.1	0.008	0.05	0.008	0.020	0.020	0.003	0.006
1.2	0.016	0.1	0.003	0.02	0.003	0.022	0.008	0.001	0.002

SECTION IV
RESULTS AND DISCUSSION

The static stability characteristics of a 0.5-scale ejection seat escape system with a stabilization parachute were determined at free-stream Mach numbers from 0.3 to 1.2. The results were obtained for both simulated rocket-off and rocket-on conditions through an angle-of-attack range from 0 to 30 deg and angle-of-yaw range from 0 to 15 deg. High-pressure air was used to simulate the rocket jet plume at a sea-level altitude.

4.1 AERODYNAMIC CHARACTERISTICS

The longitudinal stability characteristics of the escape seat model can be interpreted from the slope of the pitching-moment versus normal-force coefficient curves presented in Figs. 8, 9, and 10. These data are presented to show the effects of the stabilization parachute, bridle arrangement, rocket simulation, and yaw angles. Except for data obtained at $M_\infty = 0.3$, the comparison data presented for the model without the stabilization parachute were obtained from Refs. 1 and 2. Also, the jet-on data presented do not include the jet reaction forces and reflect only the aerodynamic effect of the jet plume on the stability of the escape system and the performance of the stabilization parachute.

The effect of the various bridle-parachute arrangements on the ejection seat longitudinal stability is shown in Fig. 8 for jet-off and jet-on conditions. The bridle assemblies investigated included one-, two-, three-, and four-attachment-point bridles. The data obtained in previous tests of the escape seat model without the stabilization parachute (Ref. 2) indicate that the model alone was longitudinally unstable for the moment reference center selected. Addition of the stabilization parachute using the four- and three-point bridle assemblies resulted in a longitudinally stable escape seat system as shown in Fig. 8a and b. The four- and three-point bridle assemblies were designed to trim the model at an angle of attack of 15 deg. The data presented in Figs. 8a and b show that the model trim angle would be near the design trim point. The one- and two-point bridle assemblies resulted in essentially a neutral longitudinally stable configuration at $M_\infty = 0.3$ and 0.6 and an unstable configuration at $M_\infty = 0.9$ and 1.2 as shown in Figs. 8c and d.

The effect of the jet exhaust on the escape seat longitudinal stability is also shown in Fig. 8 for each of the bridle-parachute arrangements investigated. At the lower Mach number ($M_\infty = 0.3$), there was a significant change in the model stability at model angles of attack near 0 deg for the four- and three-point bridle assemblies. At the other Mach numbers, and for the other bridle assemblies investigated, the nozzle exhaust flow had essentially no effect on the longitudinal stability of the ejection seat over the angle-of-attack range of this investigation.

Figure 9 shows the effect of using the various bridle-parachute arrangements on the ejection seat longitudinal stability for the jet-off condition. These data show that for zero yaw angle, the three-point bridle assembly produced the best longitudinal stability characteristics of the four bridle assemblies over the Mach number range of this investigation. The one- and two-point bridle assemblies produced essentially the same results at any particular Mach number causing the ejection seat to become neutrally stable at the lower Mach numbers and to remain longitudinally unstable at the higher Mach numbers.

The effect of varying model yaw angle on the ejection seat escape system longitudinal stability is presented in Fig. 10 using a four-point bridle assembly. For these data, the most significant variation was obtained at the higher model angles of attack ($\alpha = 25$ and 30 deg) where the ejection seat became less stable as a result of increasing the model yaw angle.

The directional static stability characteristics of the ejection seat with and without a stabilization parachute using the four-point bridle can be interpreted from the yawing-moment and side-force coefficient data presented in Fig. 11. These data indicate that for zero deg angle of attack the ejection seat without the parachute is directionally unstable through the Mach number and angle-of-yaw ranges of this investigation. As would be expected, the parachute caused a restoring yawing moment which counteracted the unstable yawing moment of the ejection seat. In general, the magnitude of the restoring yawing moment of the parachute was sufficient to cause the ejection seat to be directionally stable at all Mach numbers investigated. The directional stability of the ejection seat decreased with increasing model angle of attack.

The lateral, static stability characteristics of the ejection seat escape system can be interpreted from the slope of the rolling-moment coefficient with angle of yaw. These data, as shown in Fig. 11, indicate that for zero angle of attack, the ejection seat was laterally unstable without the stabilization parachute in the Mach number range from 0.3 to 1.2. The addition of the parachute to the seat had the effect of either decreasing the instability or exhibiting neutral, lateral stability for the Mach number and angle-of-attack ranges of this investigation.

4.2 PARACHUTE CHARACTERISTICS

The hemisflo-type parachute was used as the stabilization device for the ejection seat. Visual analysis of television monitors and motion pictures showed that the hemisflo parachute exhibited full inflation at all test conditions. All the data with a parachute were obtained at a constant parachute trail distance, X/D, of 7.8. Other trail distances using the four-point bridle assembly were investigated in Ref. 2. Photographs of the model and stabilization parachute at various test conditions are presented in Fig. 12.

The effect of the ejection seat angle of attack on the parachute drag coefficient is shown in Fig. 13 for jet-off and jet-on conditions. Generally, the parachute drag coefficient increased with increasing angle of attack with some adverse effects occurring at the high angle of attack. The effect of jet simulation on the parachute drag coefficient may also be seen in Fig. 13. The data obtained with the model at $\alpha = 0$ deg show that the jet increased the parachute drag at each Mach number. However, motion-picture coverage obtained during jet simulation showed that the jet wake had essentially no effect on the dynamics or trailing angle of the stabilization parachute. Some typical results are presented in Fig. 14 showing the effect of a parachute as a retardation device for an ejection seat. The parachute increased the ejection seat axial-force coefficient for all test conditions.

SECTION V
SUMMARY OF RESULTS

Tests were conducted in Propulsion Wind Tunnel (16T) to determine the aerodynamic characteristics of a 0.5-scale ejection seat escape system using a stabilization parachute at Mach numbers from 0.3 to 1.2 during rocket-off and simulated rocket-on conditions. The following is a summary of the results.

1. Over the test range of the investigation and for the moment reference center selected, the ejection seat model was longitudinally unstable but became stable with the parachute using the three- and four-point bridle assemblies.

2. Jet simulation had little effect on the longitudinal stability of the ejection seat with the stabilization parachute for angles of attack greater than five deg.

3. Increasing the model yaw angle from 0 to 15 deg had little effect on the longitudinal stability of the ejection seat escape system except at the high angles of attack.

4. The ejection seat model was directionally and laterally unstable through the angle-of-yaw range from 0 to 15 deg but became stable or neutrally stable with the addition of the stabilization parachute.

5. Jet simulation increased the parachute drag coefficient.

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3. Test Facilities Handbook (Ninth Edition). "Propulsion Wind Tunnel Facility, Vol. 4." Arnold Engineering Development Center, July 1971.

4. Pindzola, M. "Boundary Simulation Parameters for Underexpanded Jets in a Quiescent Atmosphere." AEDC-TR-65-6 (AD454770), January 1965.

APPENDIX
ILLUSTRATIONS

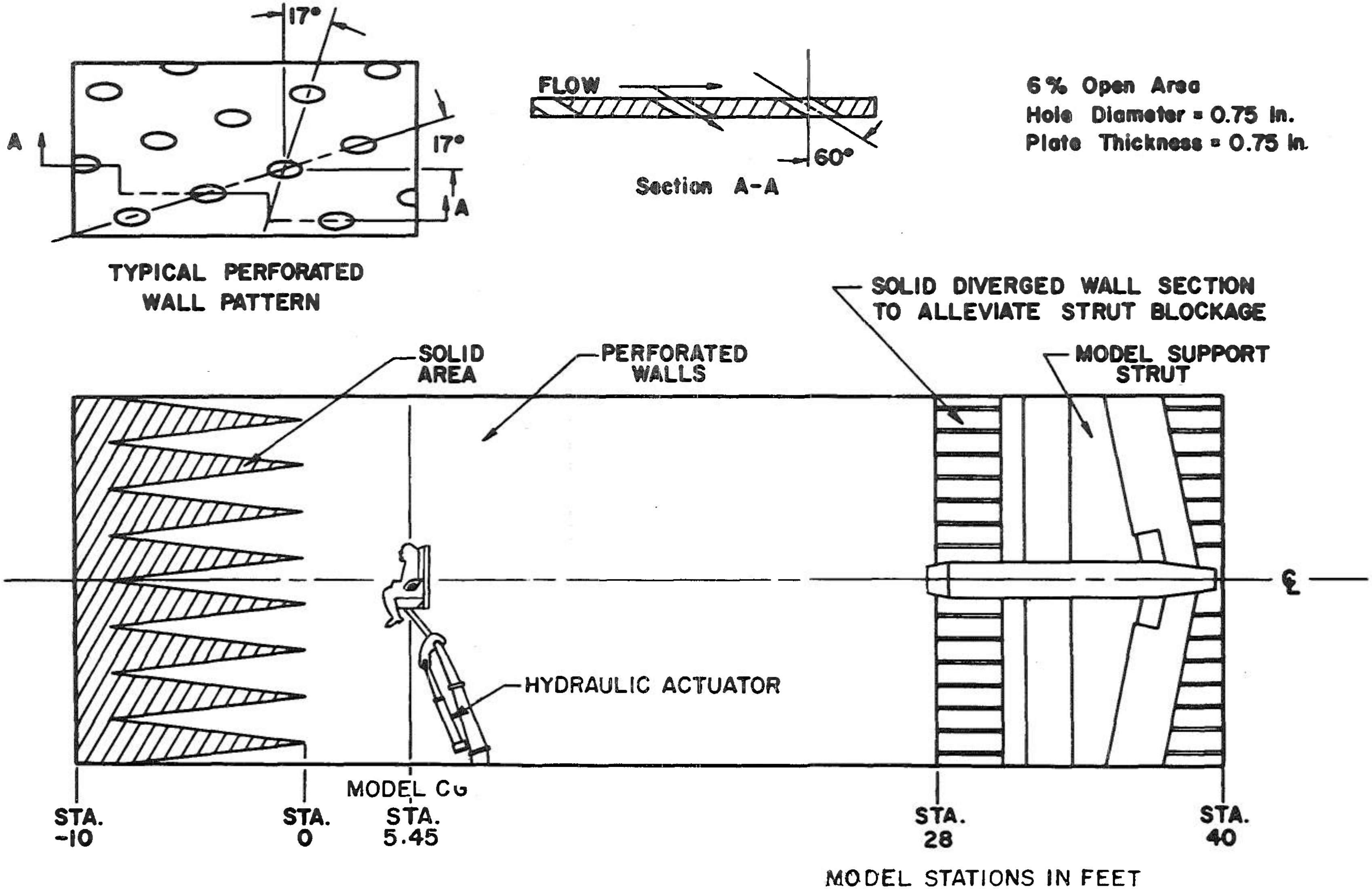
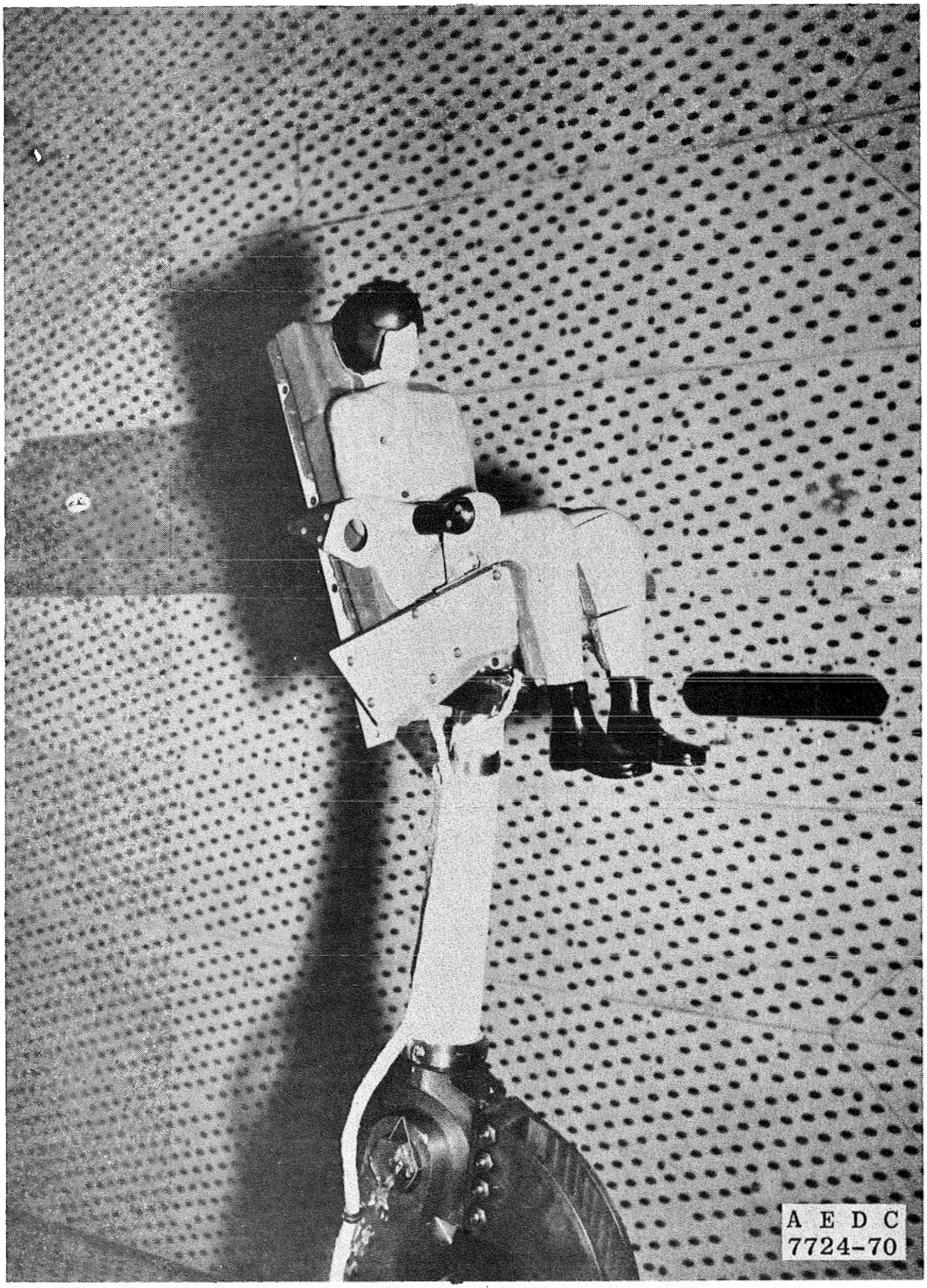
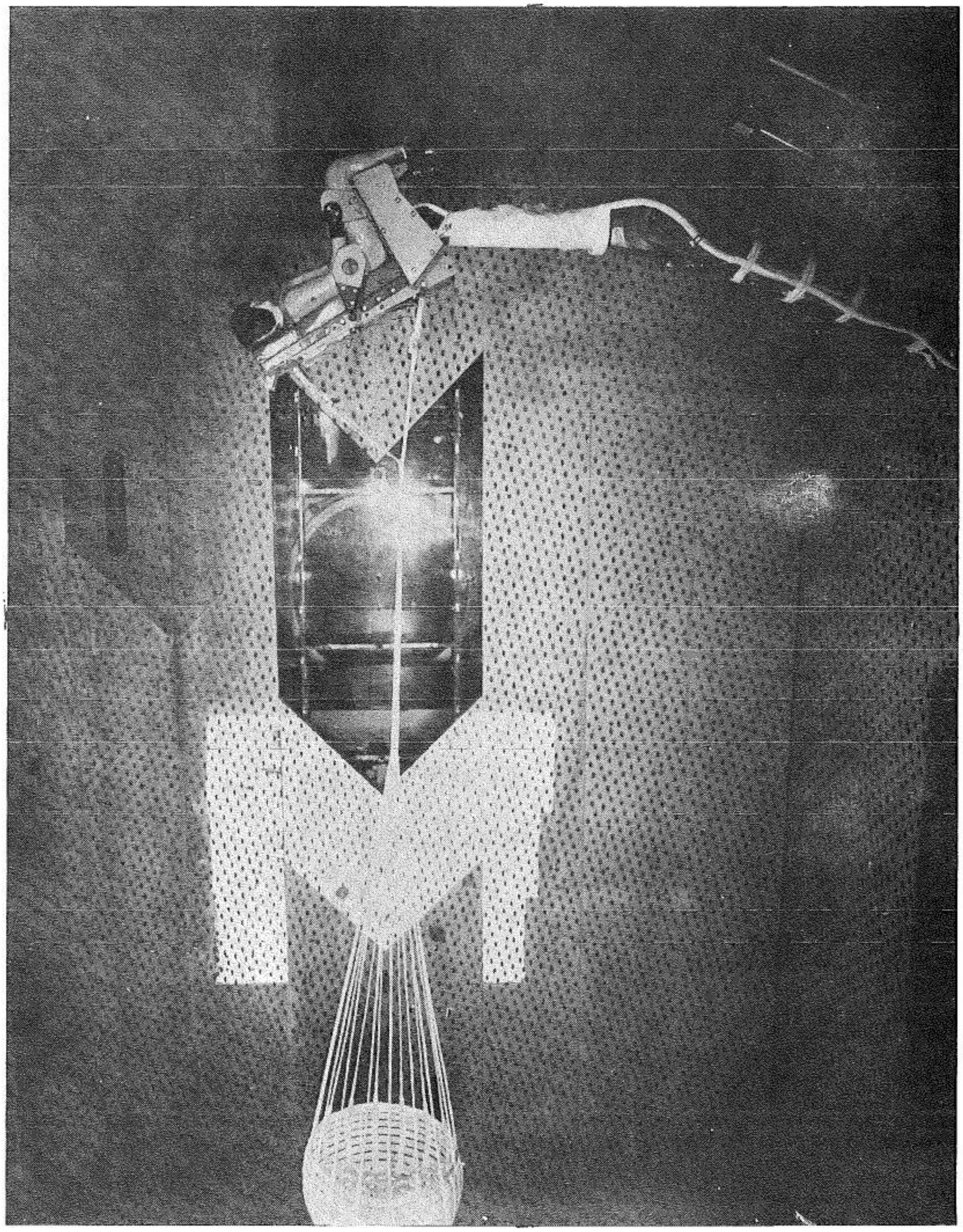


Fig. 1 Location of Model in Test Section



a. Ejection Seat Model
Fig. 2 Installation Photographs



b. Ejection Seat Model with a Parachute
Fig. 2 Concluded

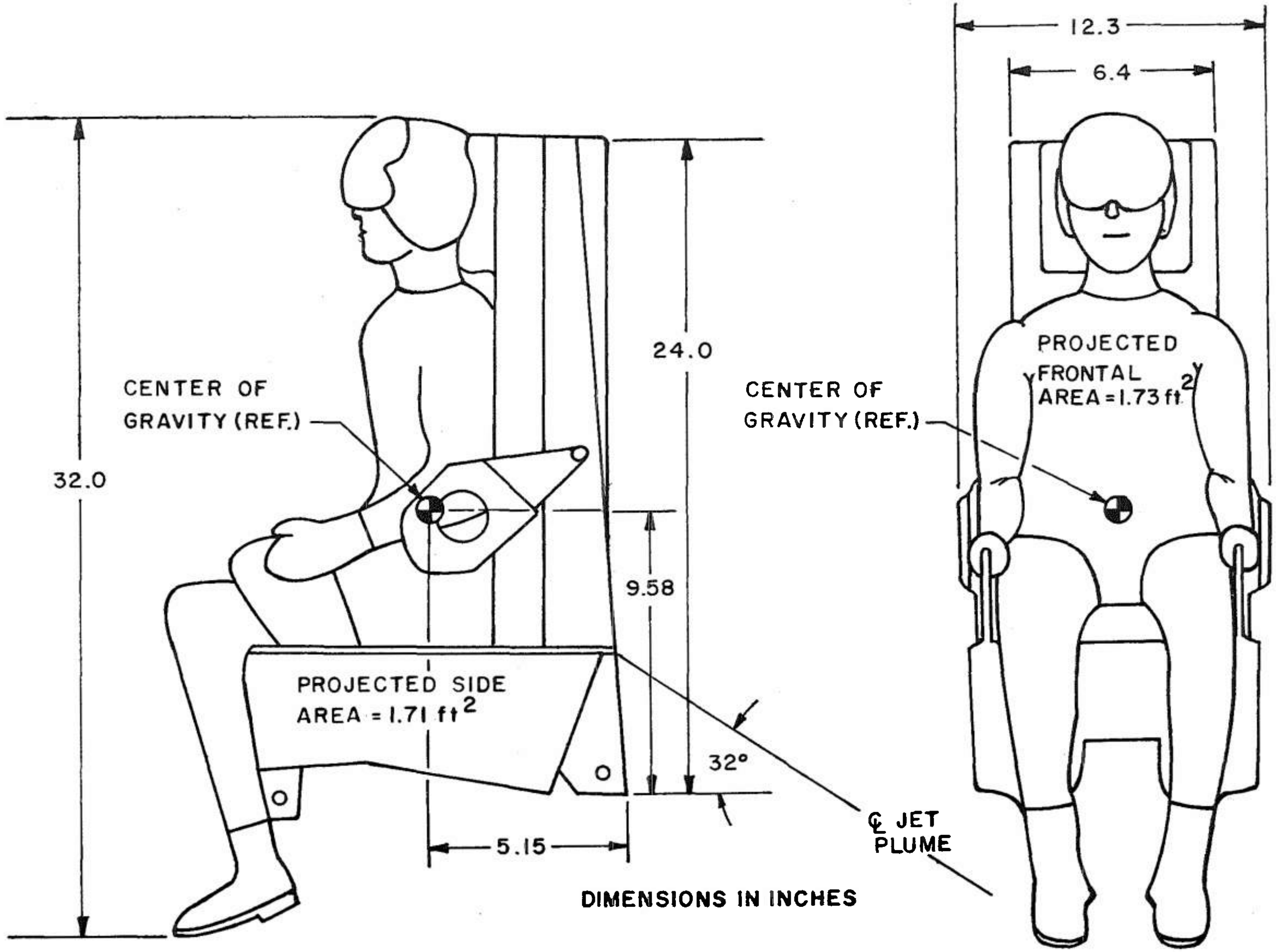


Fig. 3 Major Dimensions of the Model

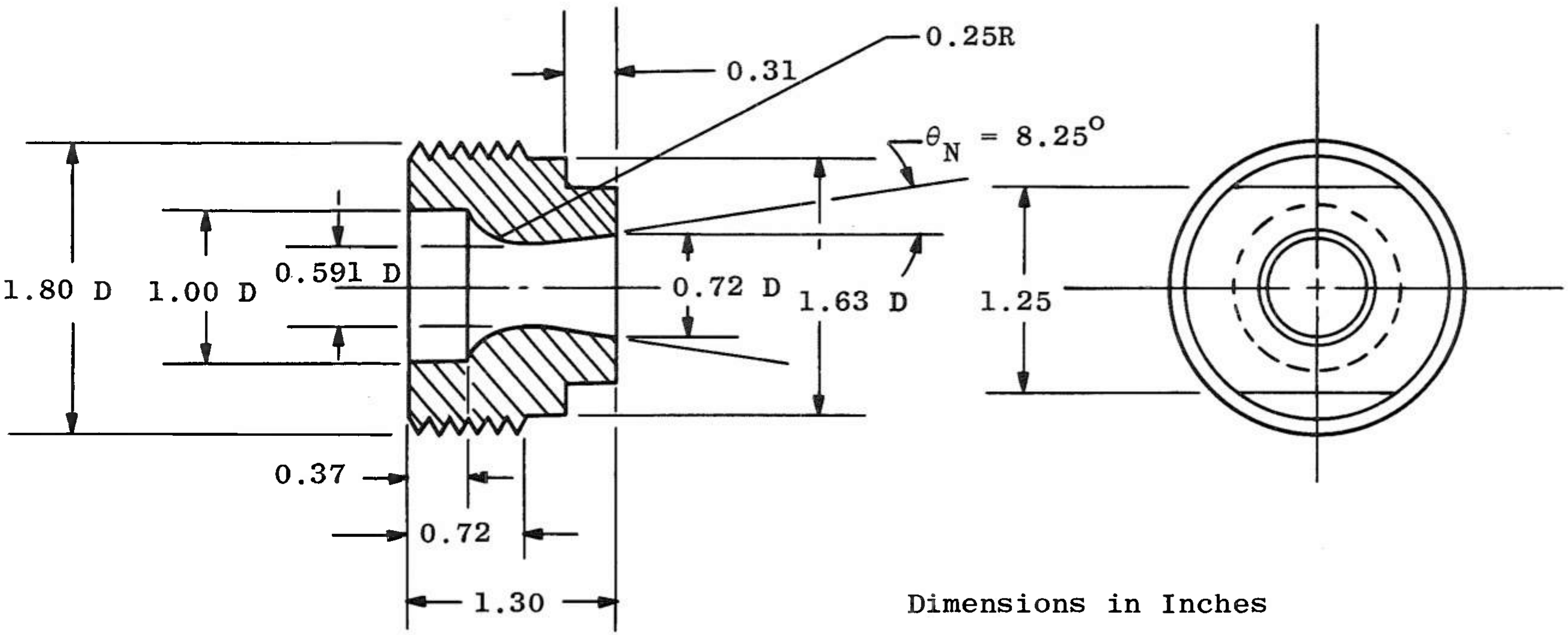


Fig. 4 Nozzle Details

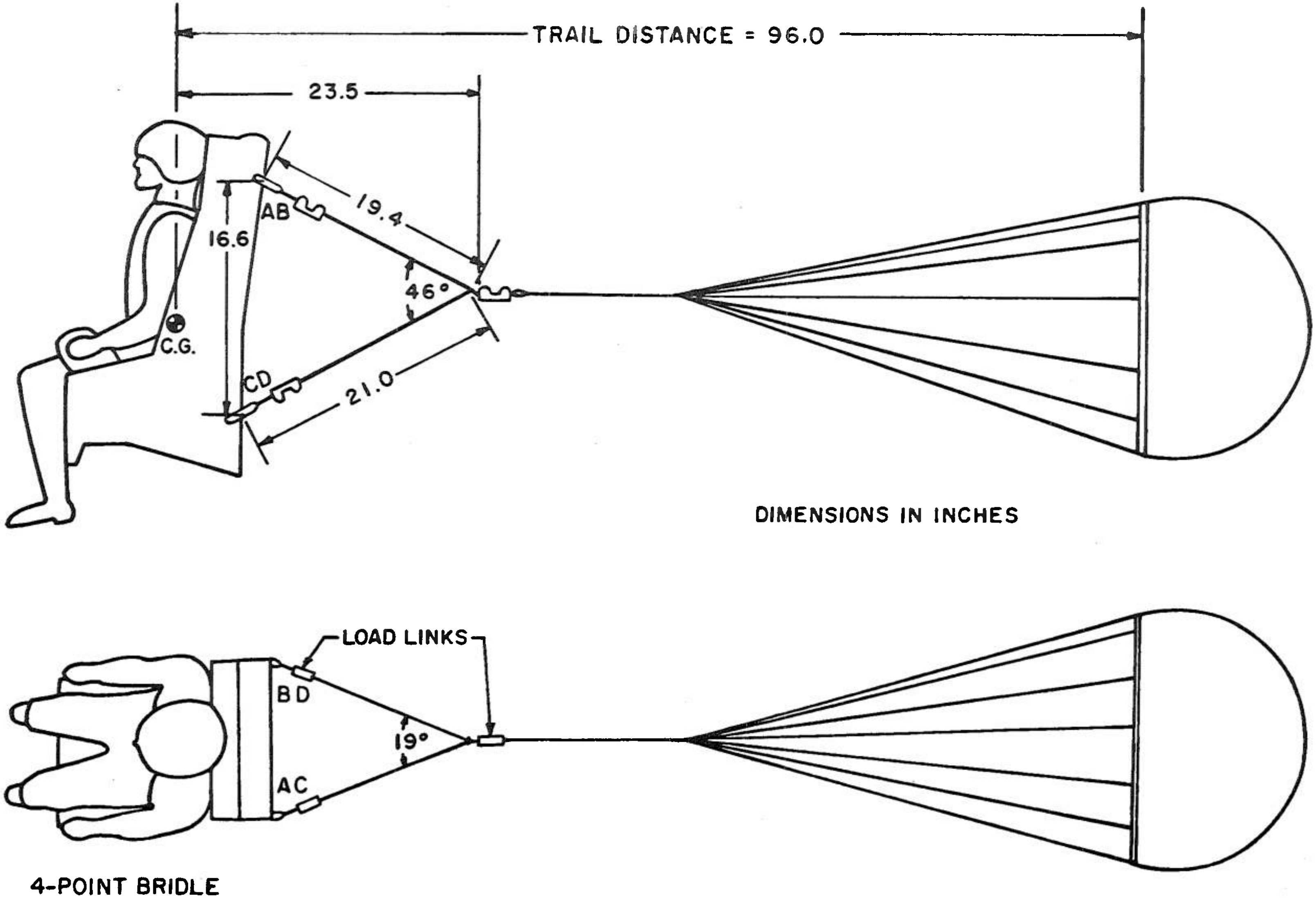


Fig. 5 General Drawing of Parachute Assemblies

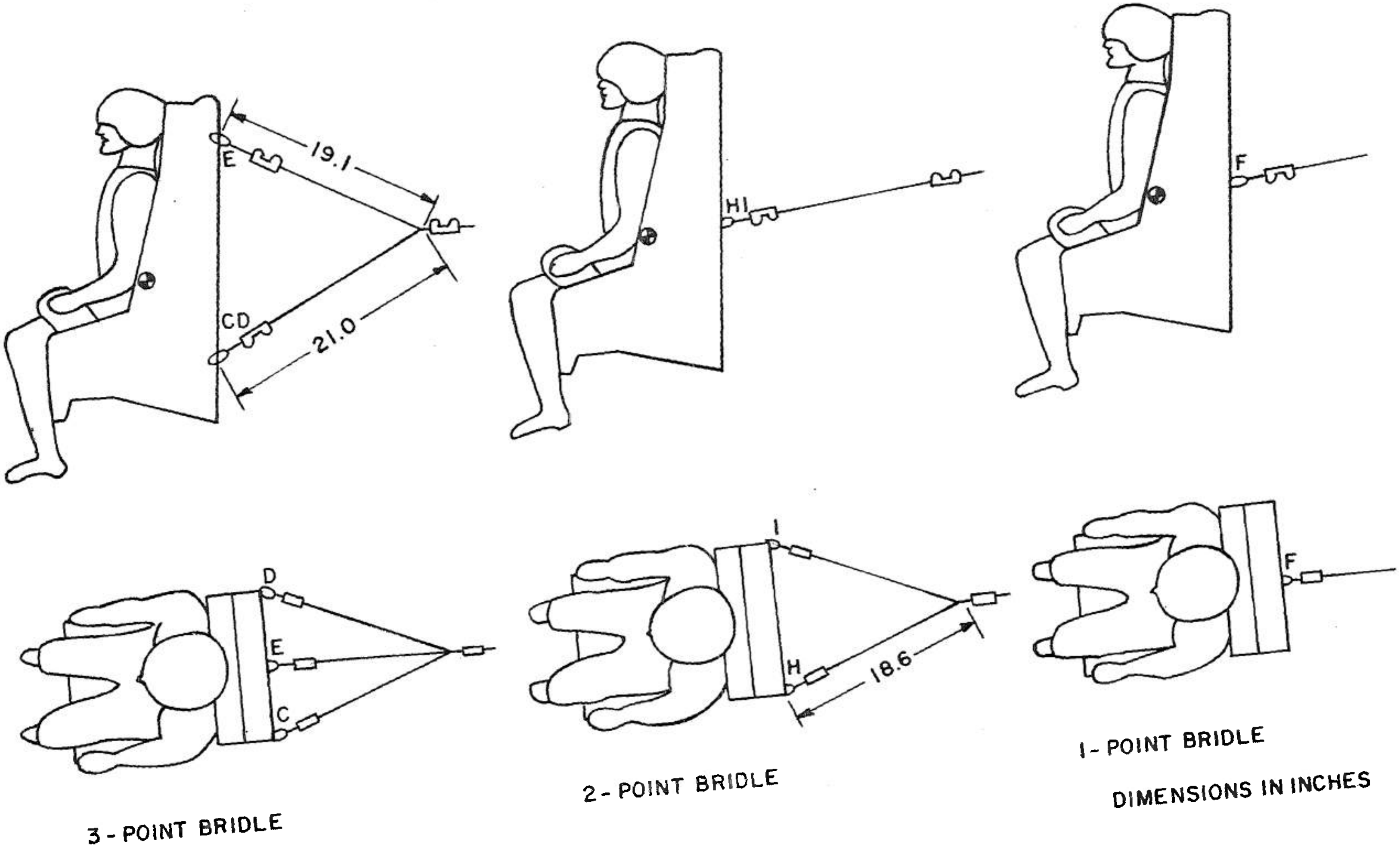


Fig. 5 Concluded

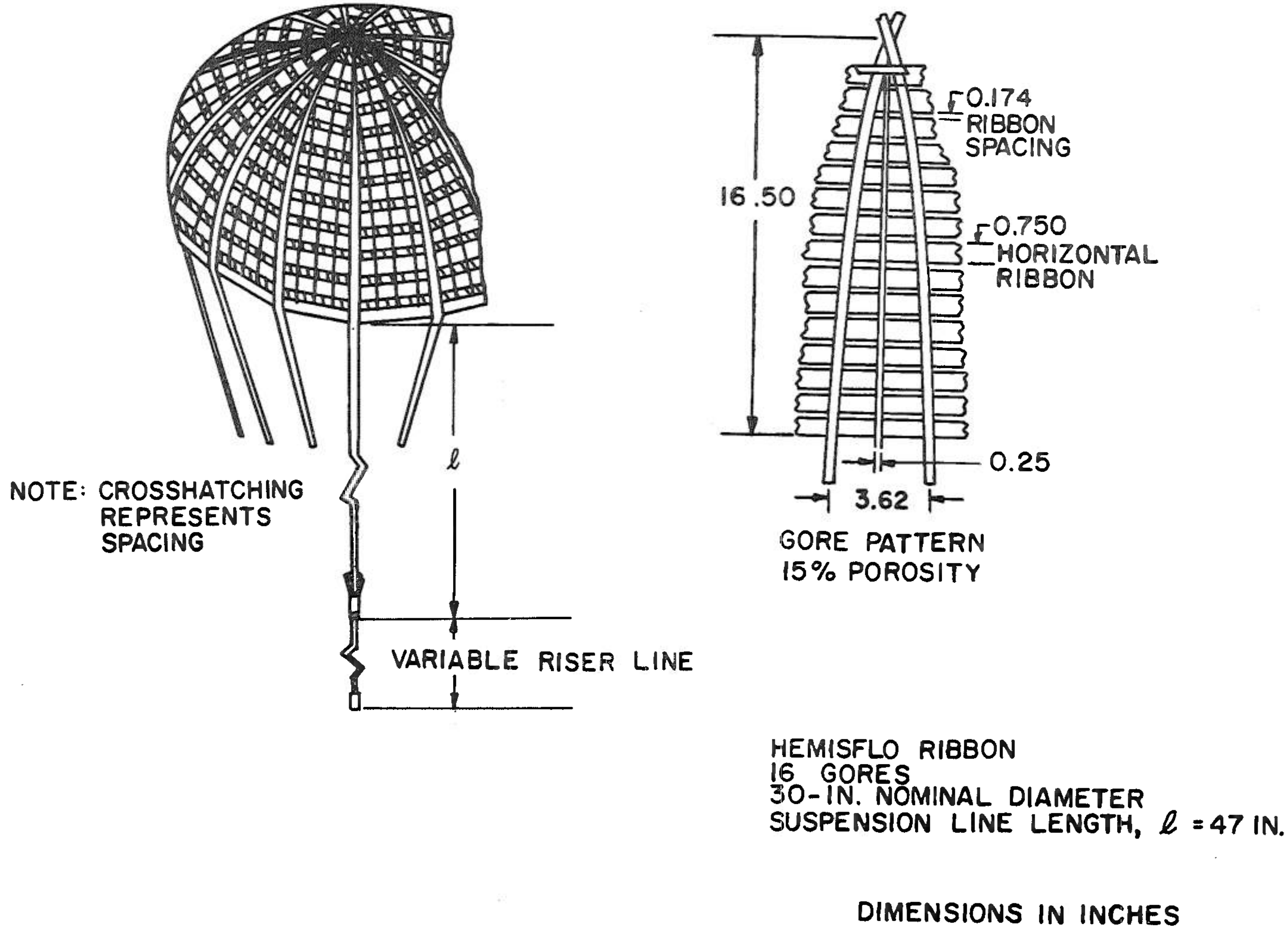


Fig. 6 Dimensioned Sketch of the Hemisflo Parachute

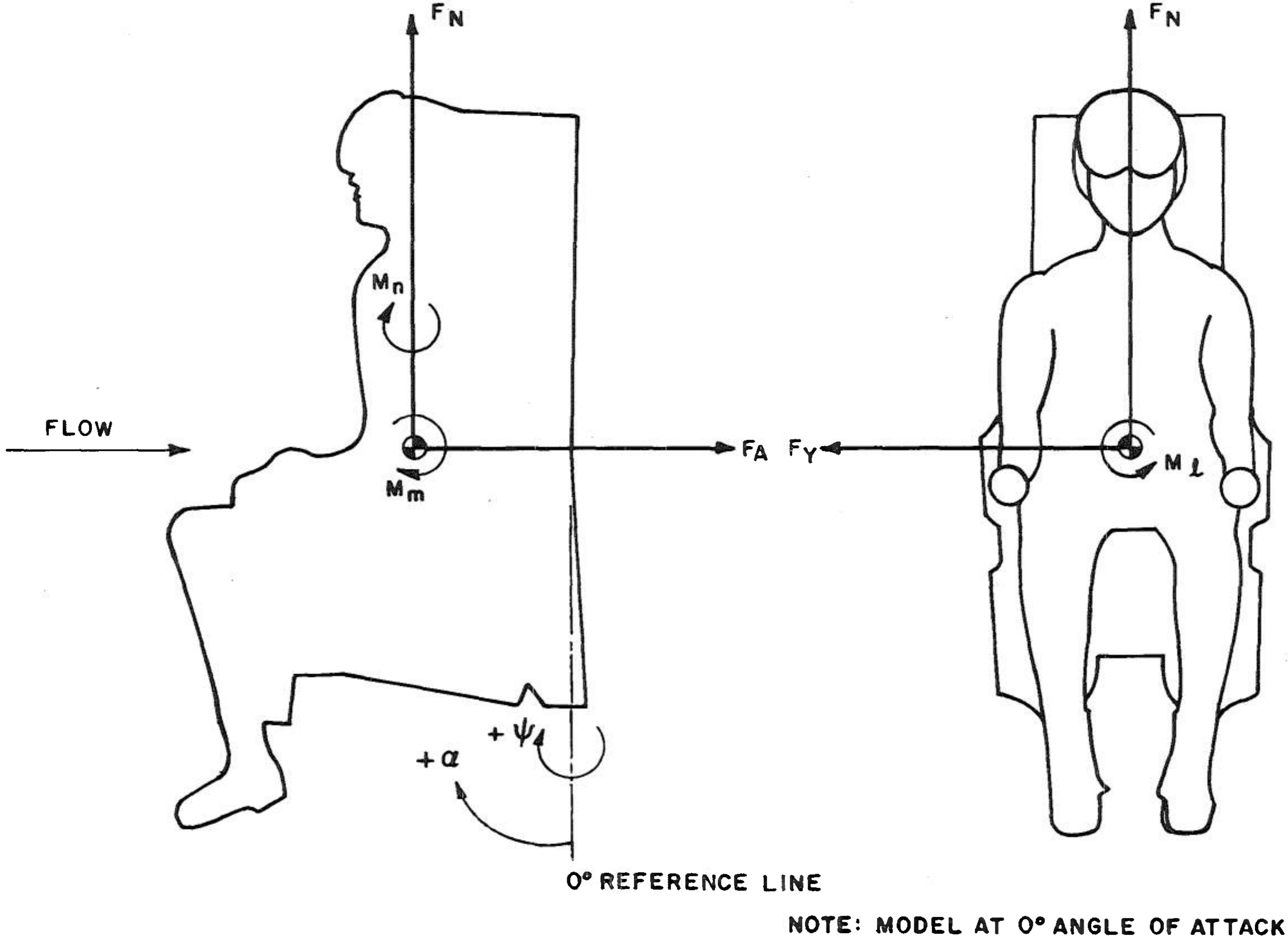
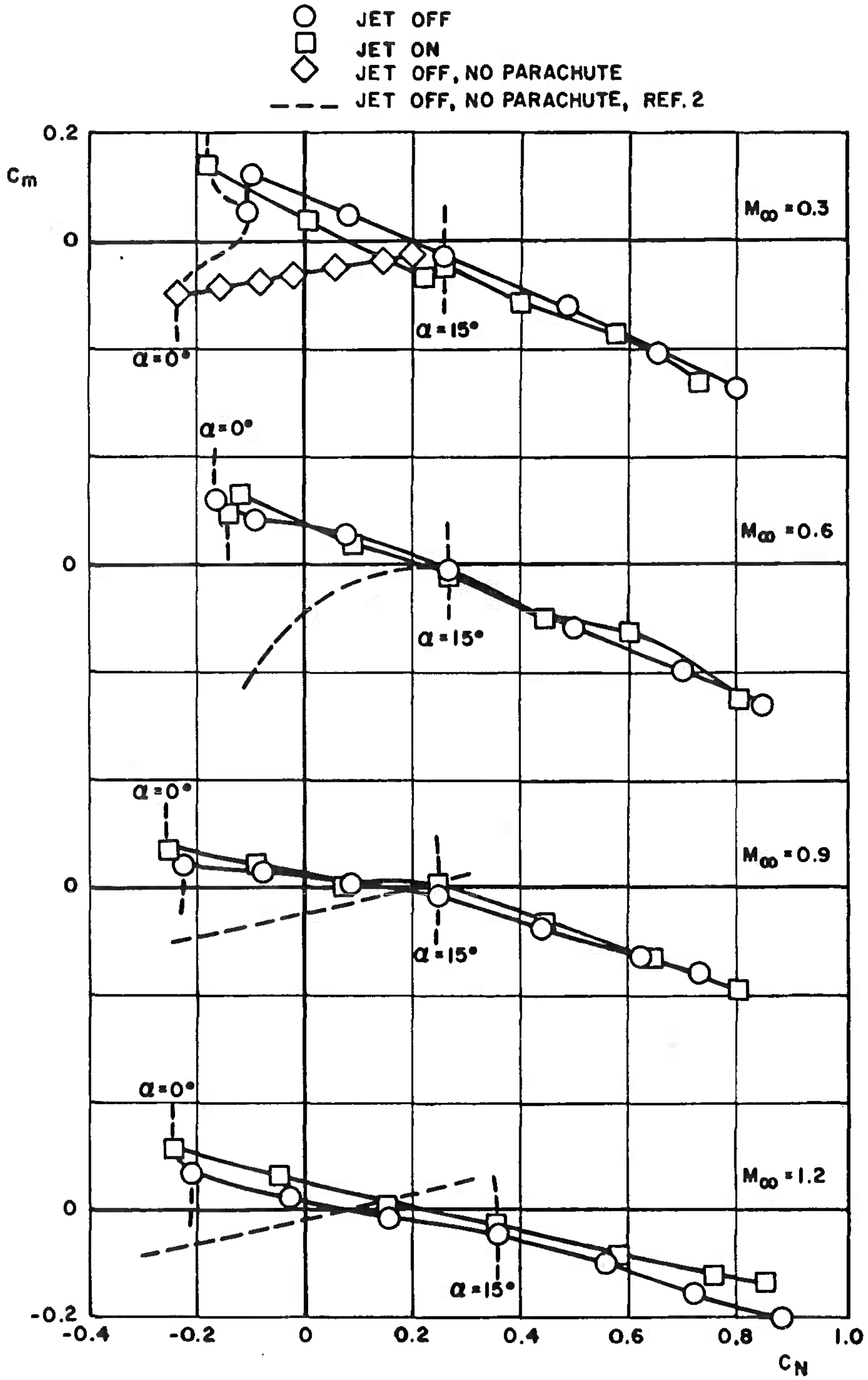
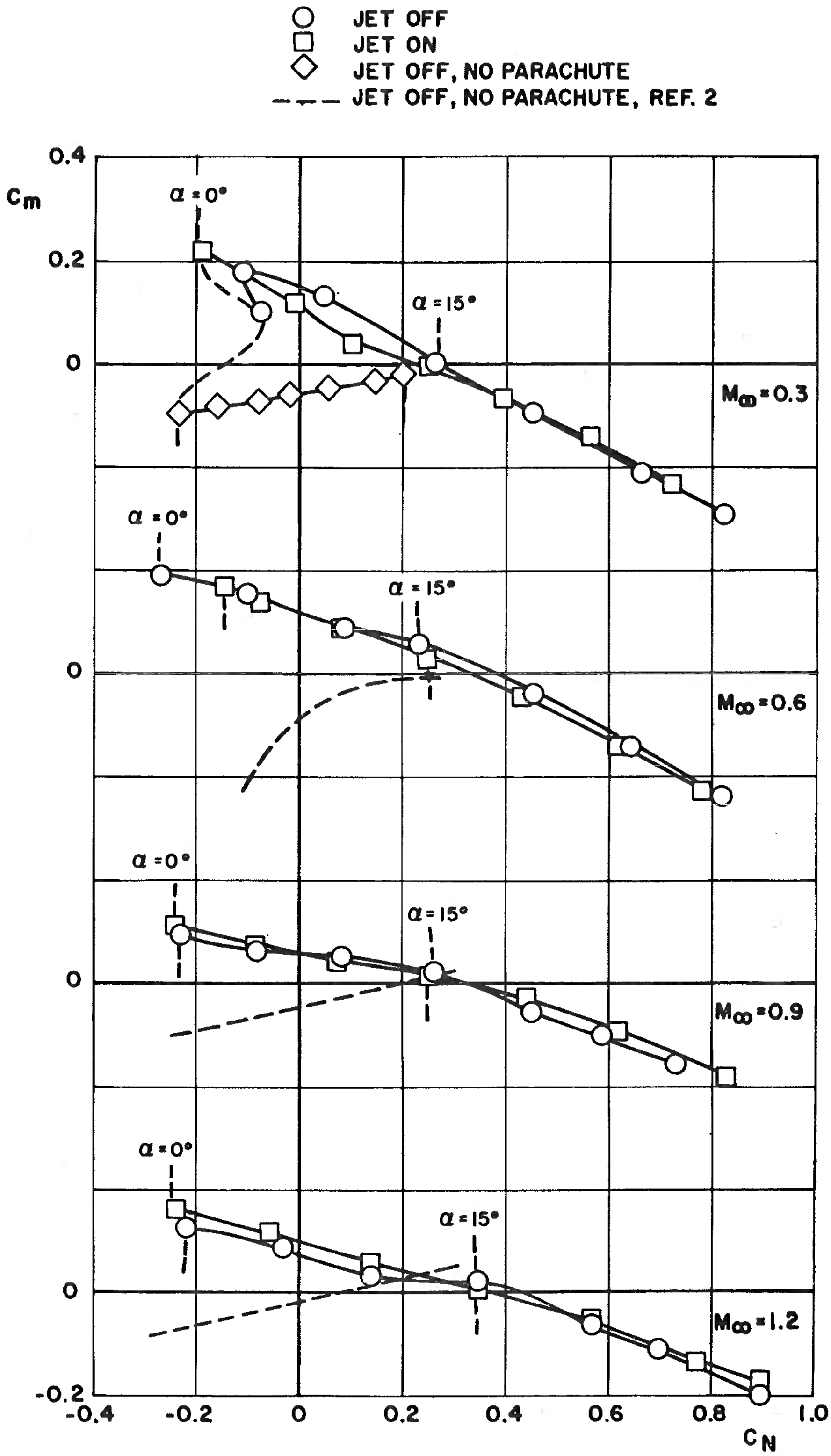


Fig. 7 Body-Axis Reference System

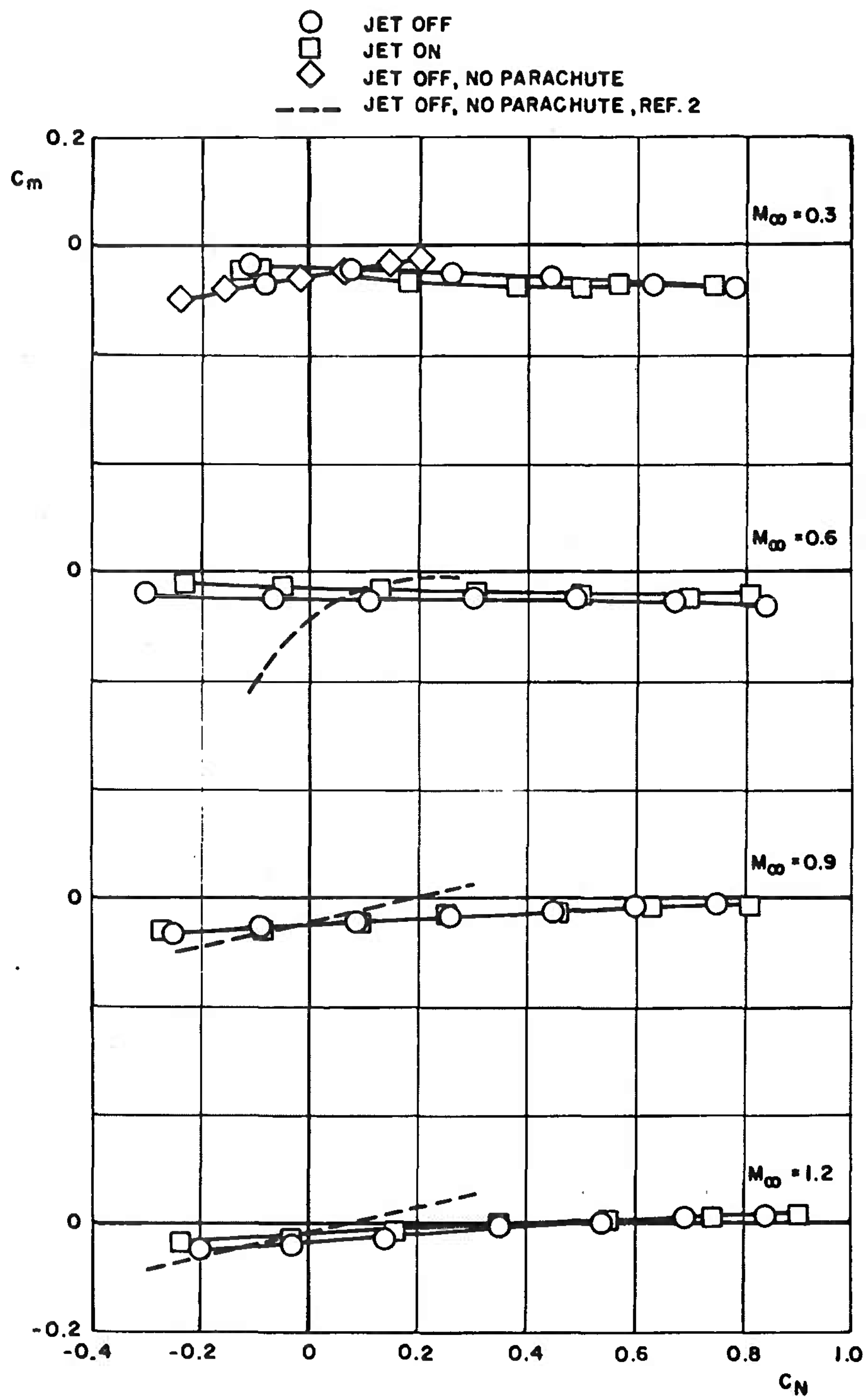


a. Four-Point Bridle Assembly

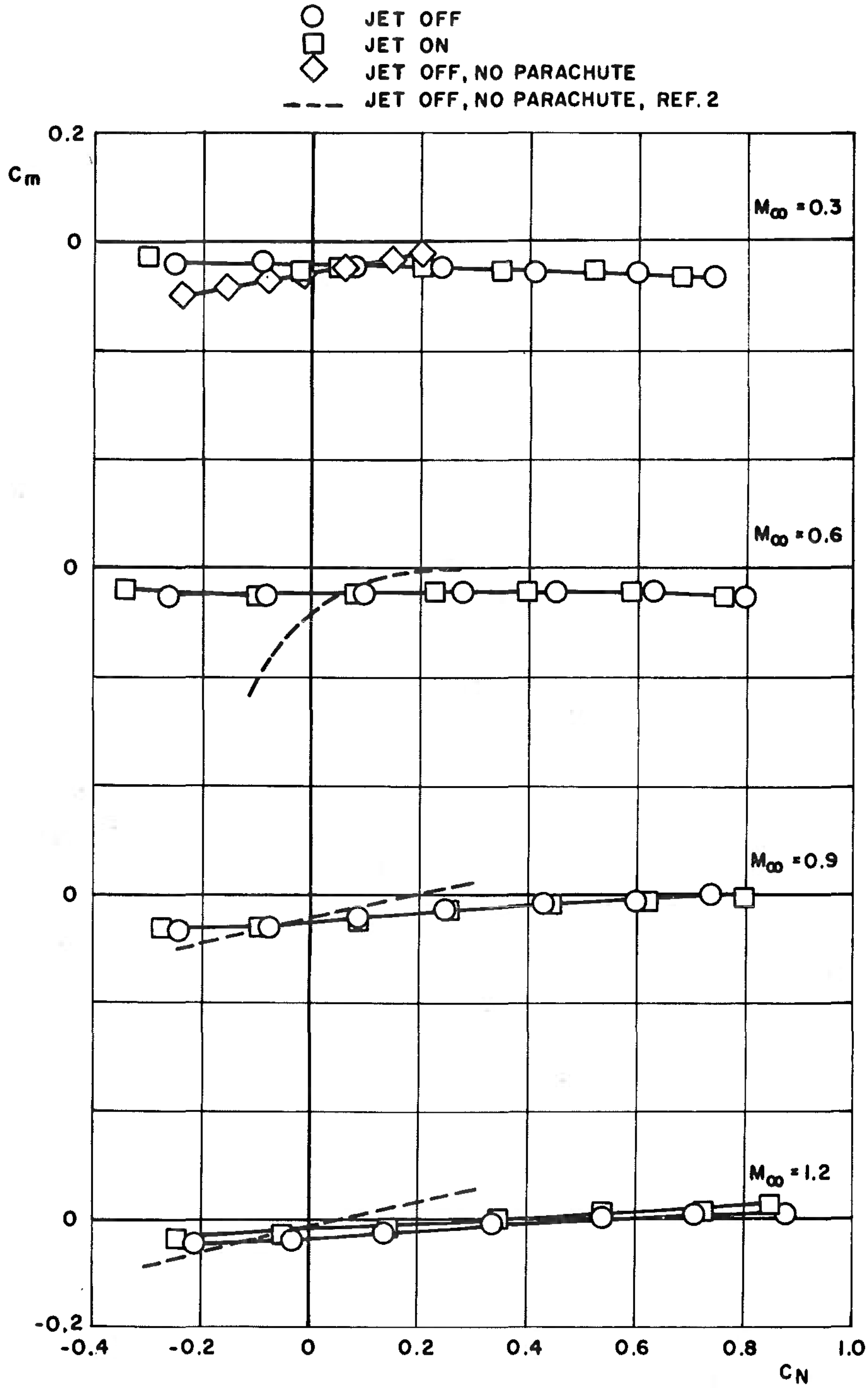
Fig. 8 Static Longitudinal Stability Characteristics of the Ejection Seat with and without a Parachute, $\psi = 0$ deg



b. Three-Point Bridle Assembly
Fig. 8 Continued



c. Two-Point Bridle Assembly
Fig. 8 Continued



d. One-Point Bridle Assembly
Fig. 8 Concluded

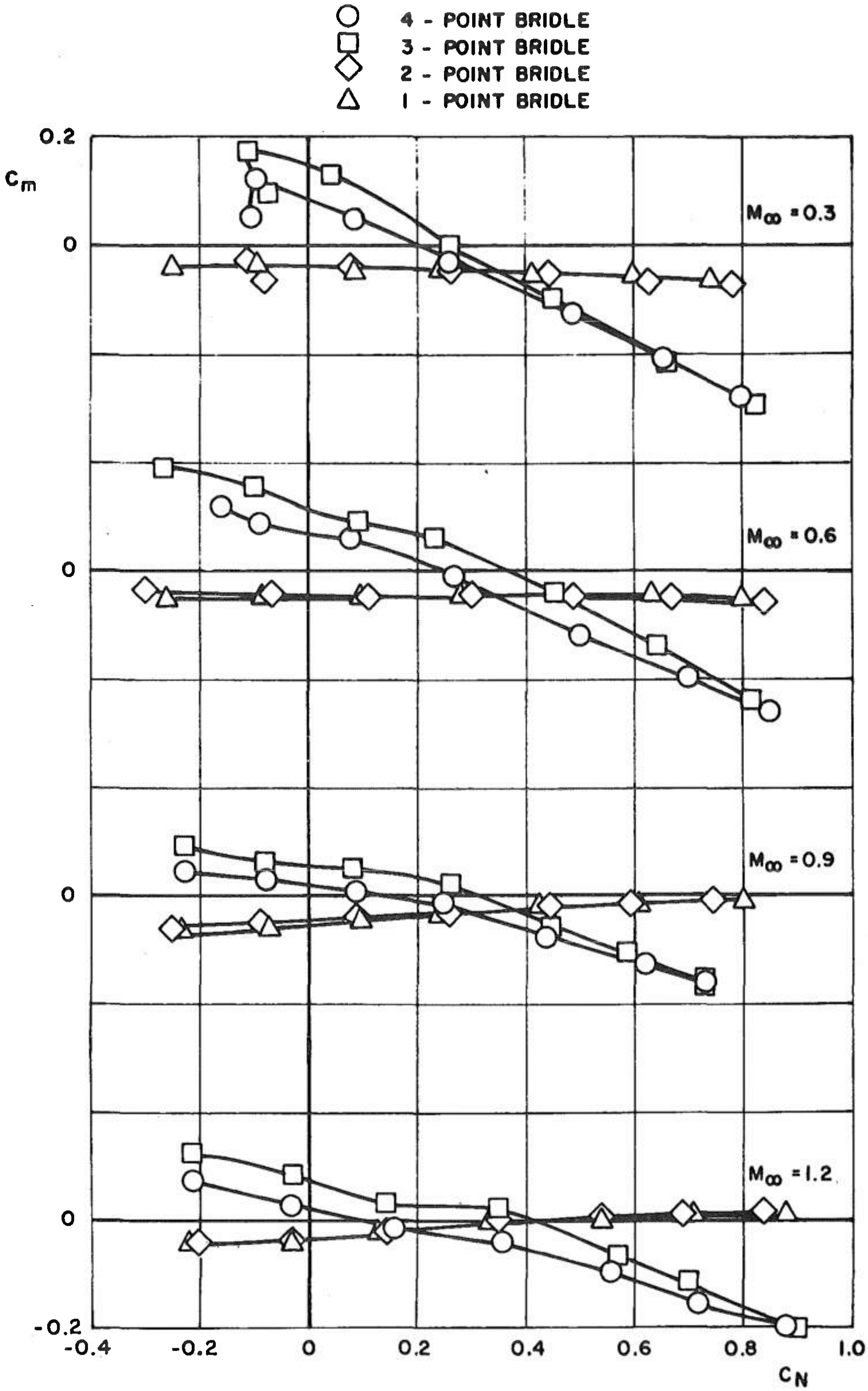


Fig. 9 Effect of Parachute Bridle Assembly on the Ejection Seat Static Longitudinal Stability, Jet Off, ψ = 0 deg

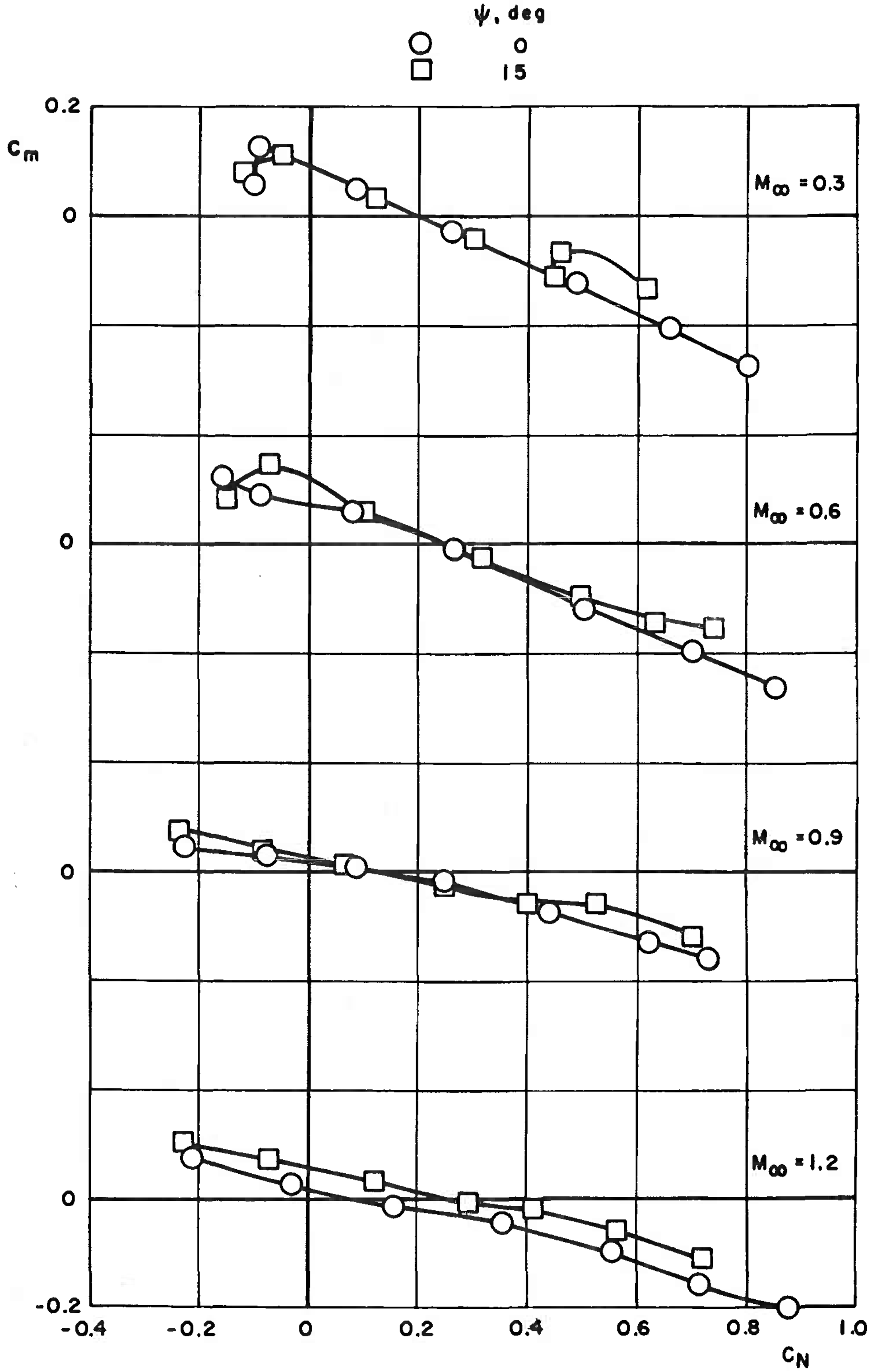
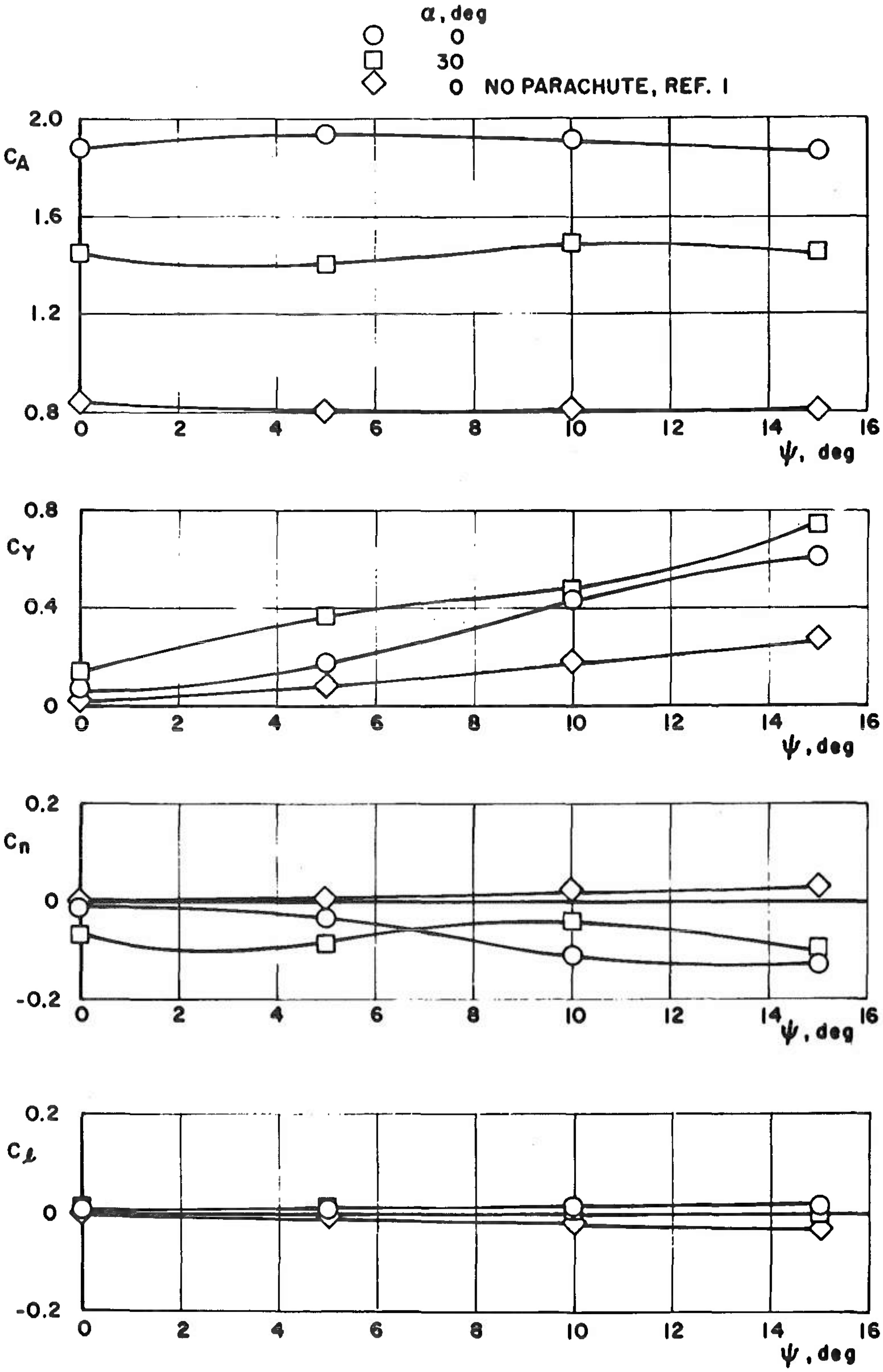
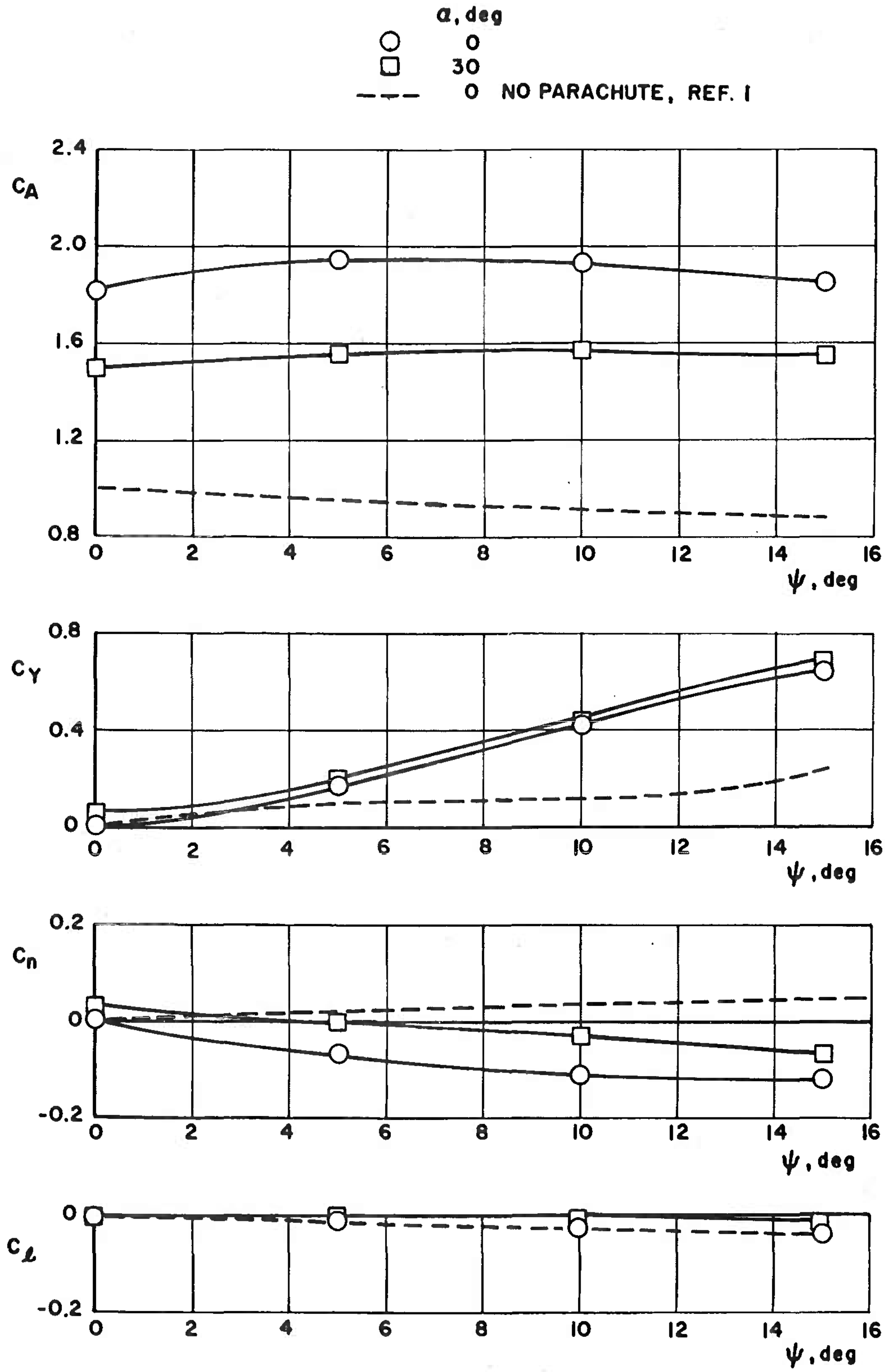


Fig. 10 Effect of Yaw Angle on the Ejection Seat Static Longitudinal Stability, Jet Off

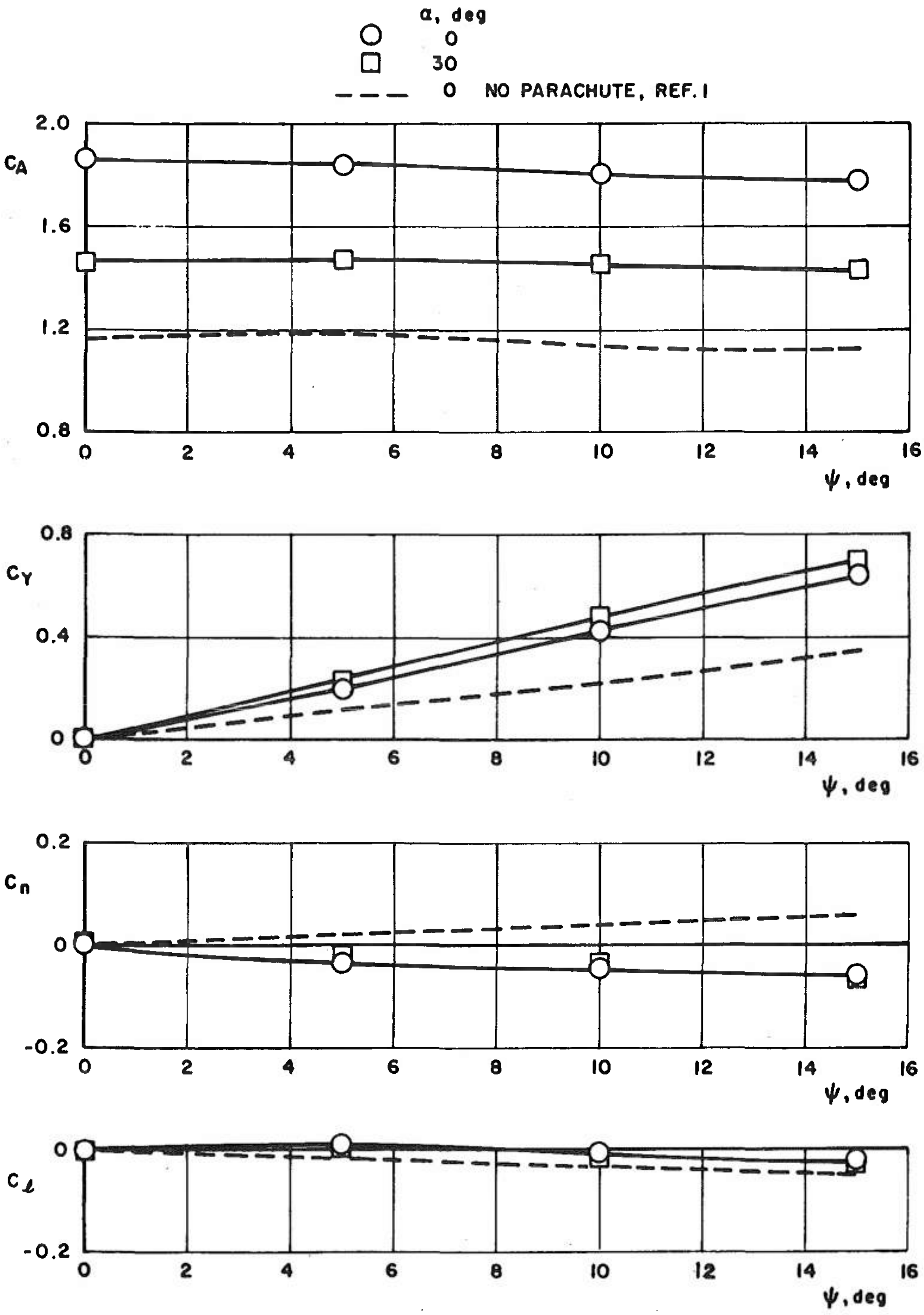


a. $M_\infty = 0.3$

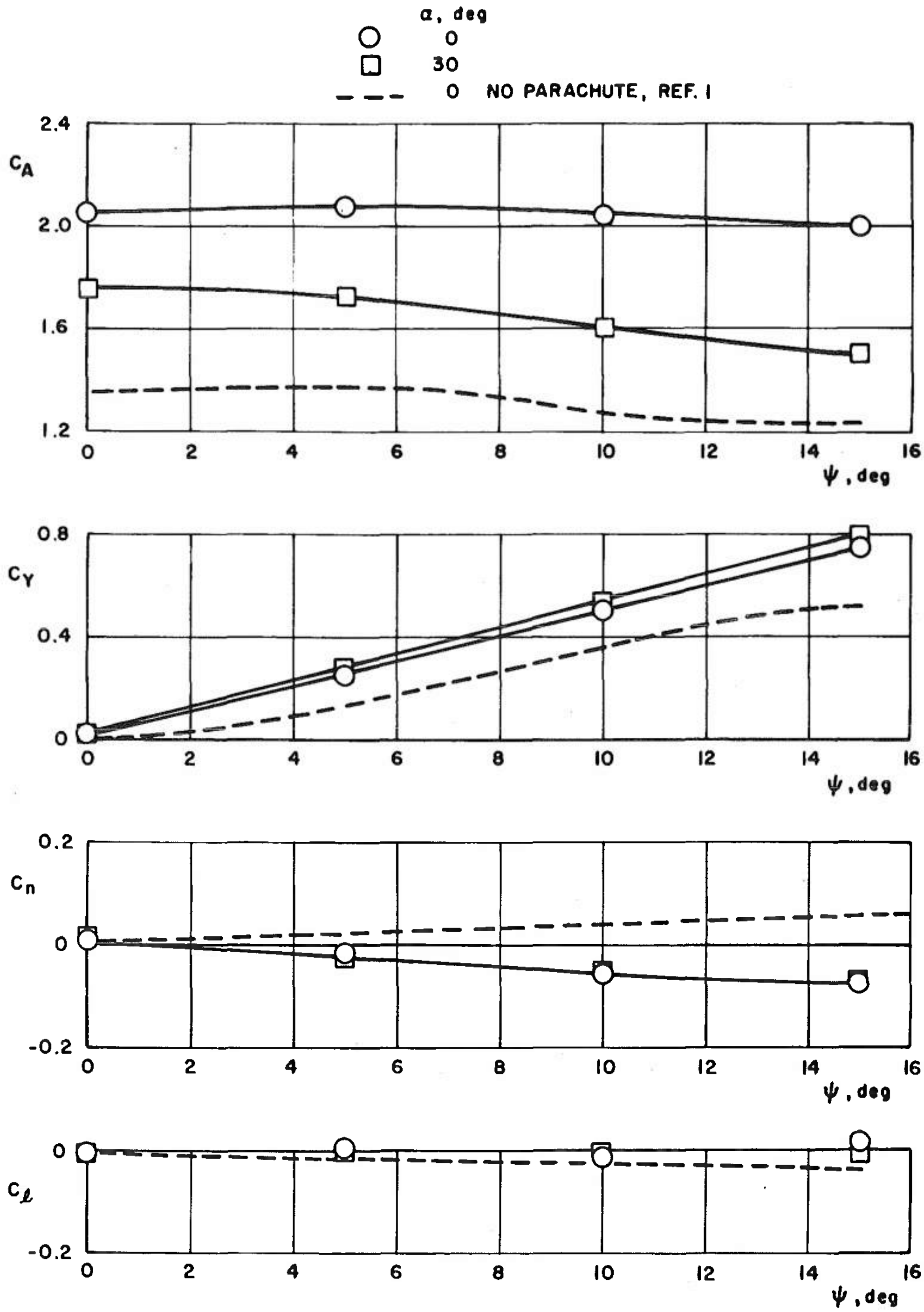
Fig. 11 Variation of Model Force and Moment Coefficients with Yaw Angle at Constant Angles of Attack, Jet Off, Four-Point Bridle



b. $M_\infty = 0.6$
Fig. 11 Continued



c. $M_\infty = 0.9$
Fig. 11 Continued



d. $M_\infty = 1.2$

Fig. 11 Concluded

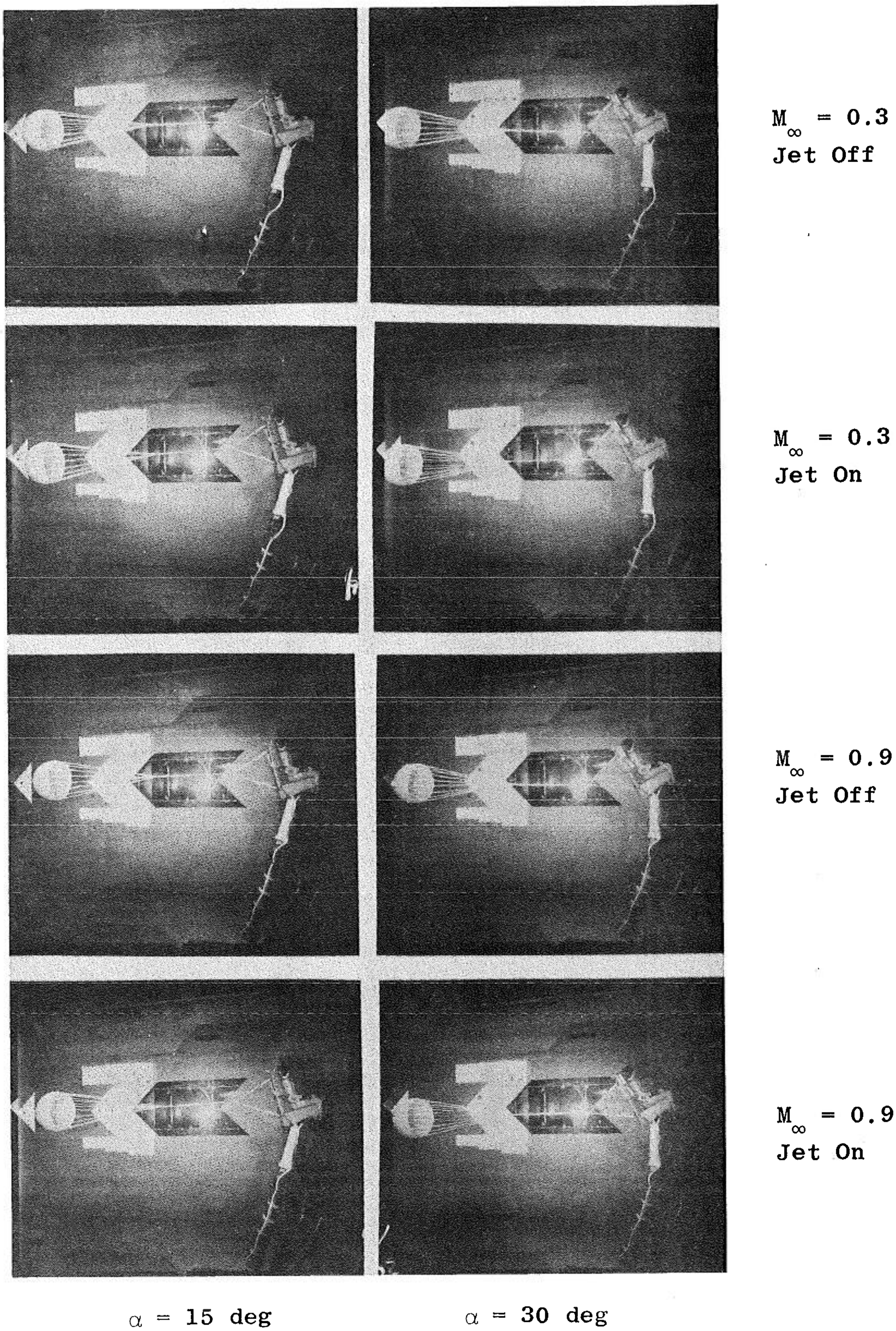


Fig. 12 Photographs of the Ejection Seat and Stabilization Parachute at Various Test Conditions, $\psi = 0$

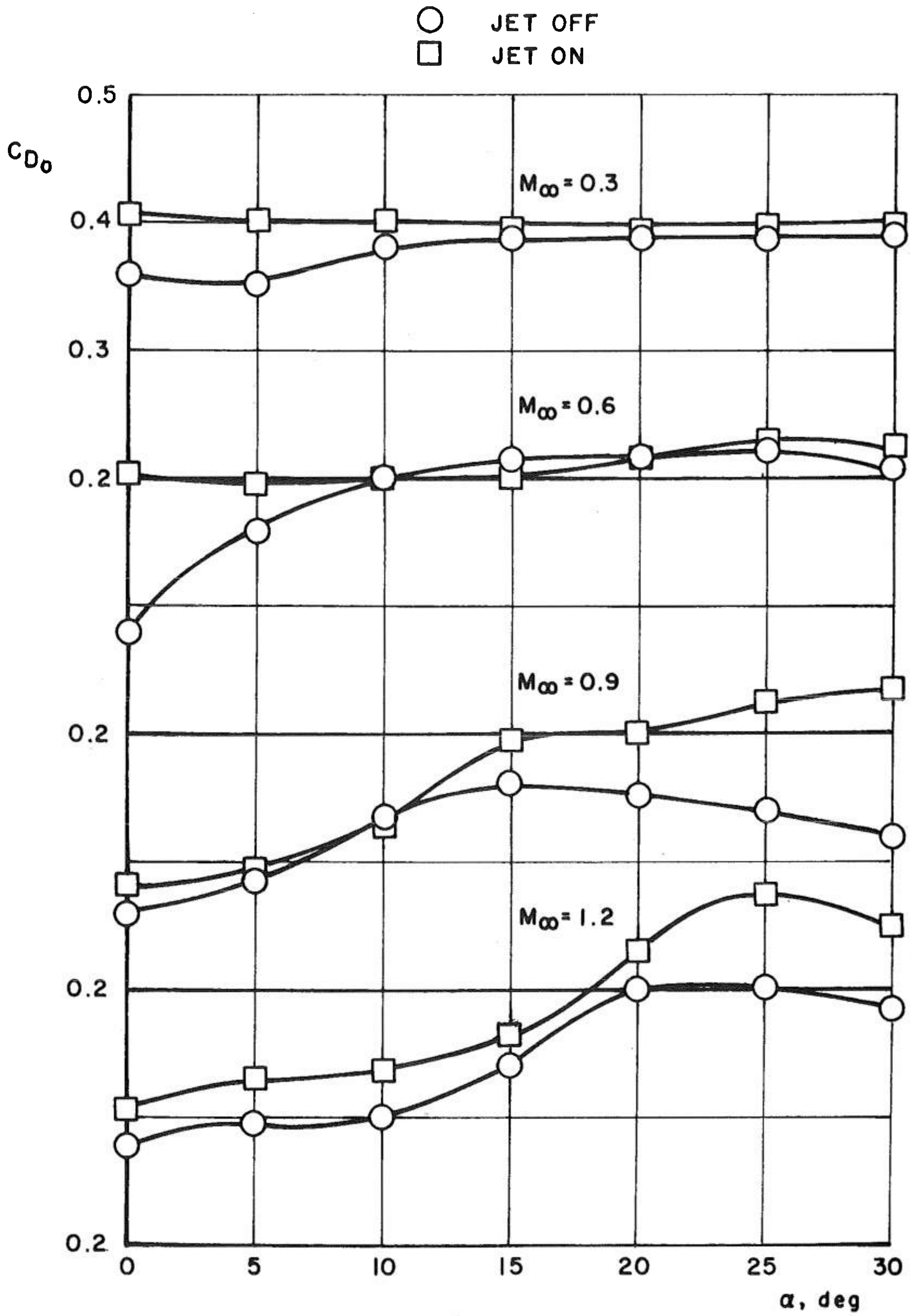


Fig. 13 Effect of Model Angle of Attack on the Parachute Drag Coefficient, ψ = 0, Four-Point Bridle

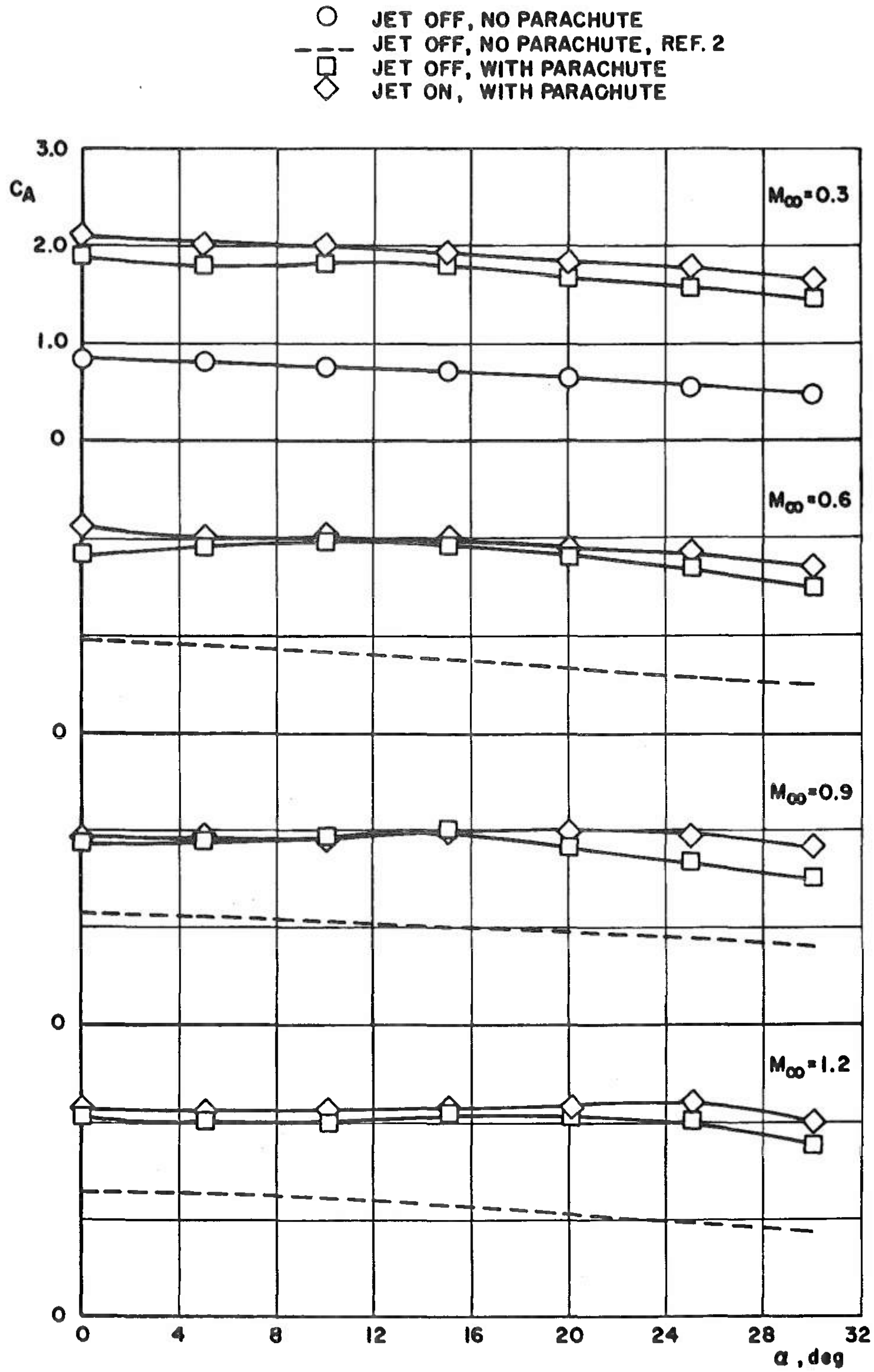


Fig. 14 Effect of Angle of Attack on the Ejection Seat Axial-Force Coefficient for Various Mach Numbers with and without a Parachute, ψ = 0, Four-Point Bridle

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13. ABSTRACT

A test was conducted in the 16-ft Transonic Wind Tunnel of the Propulsion Wind Tunnel Facility to determine the aerodynamic characteristics of a 0.5-scale ejection seat escape system and to determine the stability effects of a stabilization parachute attached to the back of the ejection seat model. The results were obtained for both simulated rocket-off and rocket-on conditions through a model angle-of-attack range from 0 to 30 deg and an angle-of-yaw range from 0 to 15 deg. High-pressure air was used to simulate the escape rocket jet plume at a sea-level altitude. Over the test range of this investigation, the results show that the ejection seat model was statically unstable but became longitudinally and directionally stable with the parachute using the three- and four-point bridle assemblies. Jet simulation and model yaw angle had little effect on the ejection seat longitudinal stability; however, jet simulation increased the parachute drag coefficient.

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